Removal of fine-grained and thin filter cakes by a counter-current backwash treatment

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In industrial solid/liquid separation, the removal of fine particles (≤ 10 µm) in a suspension with a low solids content (0.01-1 v/v %) is a challenging and demanding task. This application takes place in a wide array of industrial production such as metal processing and treatment industries. In order to achieve the required purity, different types of filters like candle and leaf filter can be used. In Figure 1, the commonly used candle filters are shown inside the vessel (a), during filtration (b), and cake removal (c).

In respect of the field of applications, the procedure of removal has revealed that there is potential for improvement in pressure difference and amount of backwash reflux. These process variables highly depend on the material properties like cohesion within the filter cake and adhesion of the filter cake onto the filter media. In order to guarantee the removal of the filter cake, the applied removal force has to be larger than the adhesive forces. Furthermore, to remove the filter cake in large fragments, the removal force has to be lower than the cohesive force. These two effects also depend on porosity, pH-value, and further properties; they can be reflected by and measured as shear and tensile strength of the filter cake.

Currently, the amount of backwash reflux is oversized and leads to an operating point below the optimum. Hence, research must be carried out how to improve the backwash treatment in respect of the process conditions in an economic and process-technical context.
This presentation comprises a state-of-the-art review of the current backwash filters and differentiate between the various physical principles of cleaning process. Moreover, the project and experimental facility will be presented, followed by first results.

Keywords

Backwashing filter, Filter cake discharge, Adhesion, Cohesion

FILTECH 2016
Cologne, Germany, 11-13 October 2016, www.filtech.de
Abstract

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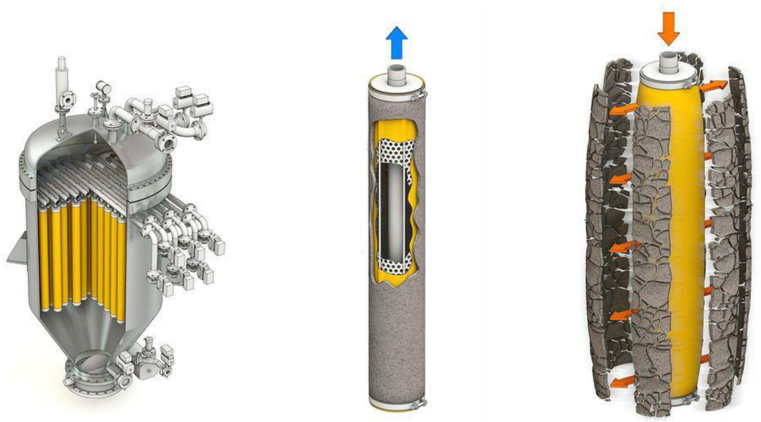

a) b) c)

Figure 1: Candle filters arranged inside a vessel (a), during filtration respectively cake build-up (b), and cake removal through backwash (c), courtesy of BHS-Sonthofen GmbH

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In industrial solid/liquid separation, the removal of fine particles (≤ 10 µm) from a suspension with a low solids content (0.01-1 v/v %) is a challenging and demanding task. This process occurs in many areas of industrial production such as metal processing and treatment industries. Further fields of application are the clarifying filtration of aluminium hydroxide (Bayer-Process) and filtration of silicon particles in semiconductor technologies. In order to achieve the required purity, different types of filters like candle and leaf filters are commonly used.

In addition to the main filtration process step, the regeneration of the filter cloth is necessary to improve the process performance with regards to the filtrate flow and filtration pressure. In the case of a fixed pressure drop Δp, the regeneration begins when a specified minimum volumetric flow $\dot{V}_{F,min}$ is reached. This value will be determined by the existing pressure system, strength of the used filter cloth and, of course, economic aspects. For a fixed filtrate flow $\dot{V}_F$, the regeneration should be triggered by a maximum pressure drop Δp_{max} and the corresponding filter cake thickness. Design of the filtration procedure with regards to economic factors is already available in the open literature [1]. In Figure 1, the two process conditions are shown using an example process sequence provided by Melin et al. [2].

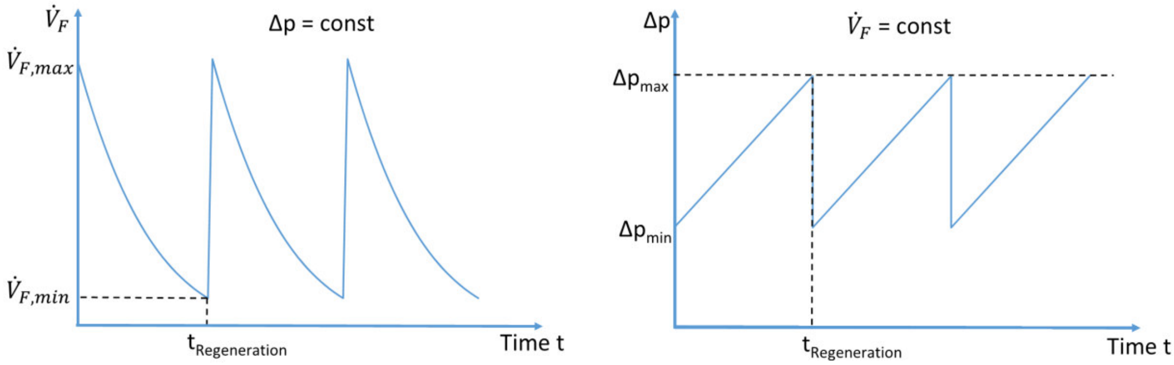


Figure 1: Operating conditions in filtration process for constant pressure difference (left) and constant filtrate flow (right), based on Melin et al. [2].

The regeneration of a filter cloth is defined by the process conditions during filtration and requires little time compared to the whole filtration process. With regards to continuous process improvement, regeneration of such filter cloth through backwash treatment is based on the experience of the industrial user and/or requires experimentation to determine the required backwash pressure and volumetric flow for a well cleaned filter cloth. This may sometimes lead to an oversized backwash volume to regenerate the filter cloth or, in other case, to a poorly cleaned filter cloth. An oversized backwash volume increases the filtrate hold-up and the corresponding plant design during a poor cleaned filter cloth directly decrease the process performance. Current literature only refers to improving the filter by decreasing surface roughness and provides no information as to the required regeneration process conditions [1]. In addition, cake removal mainly concern to "dry cake removal" into a gas phase without any method to define the backwash process conditions [3, 4]. Research from the last few years has focused on the improvement of metal-edge filters [5] or regeneration of the filter cloth from single adhering particles [6]. A catalogue of measures however, for regeneration of filter clothes through a backwash treatment does not exist and will be examined within the context of this project. In Figure 2, the commonly used candle filter is shown during filtration, and regeneration with the characteristic cake removal.

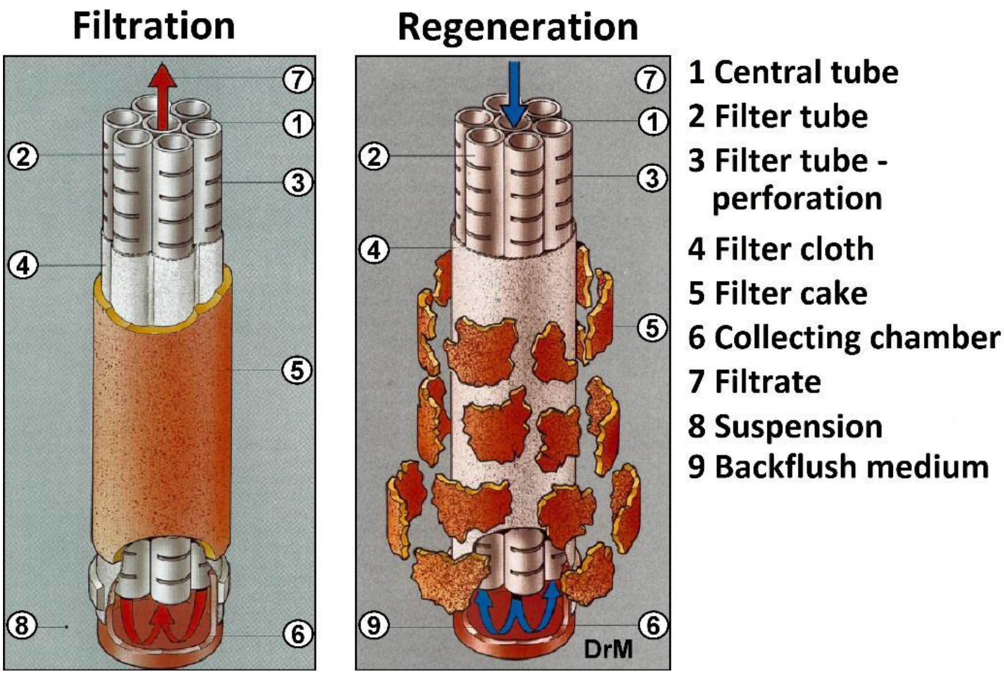


Figure 2: Candle filter during filtration cake build-up (left), and cake removal through backwash (right), based on Dr. Müller AG

Weigert et al. has demonstrated a method for evaluating the adhesive forces between filter cloth and filter cake through a shear cell for filter press [6]. The boundary conditions are based on the elementary mechanics of bulk solids and the related Mohr's Circle for stress and strain analysis. The required detachment stress can be determined through the shear stress τ_c between the filter cloth and the first layer of filter cake for a filter cake with water saturation < 1. The transfer to an application in backwash treatments for cake discharge by a counter-current flow in liquid phase is not adequately investigated. In Figure 3, the contact between the first particle layer and the filter cloth is shown schematically with the supposed force balance (left) and Mohr's Circle for stress and strain analysis and the graphic evaluation of cohesion τ_c and tensile strength σ_z (right).

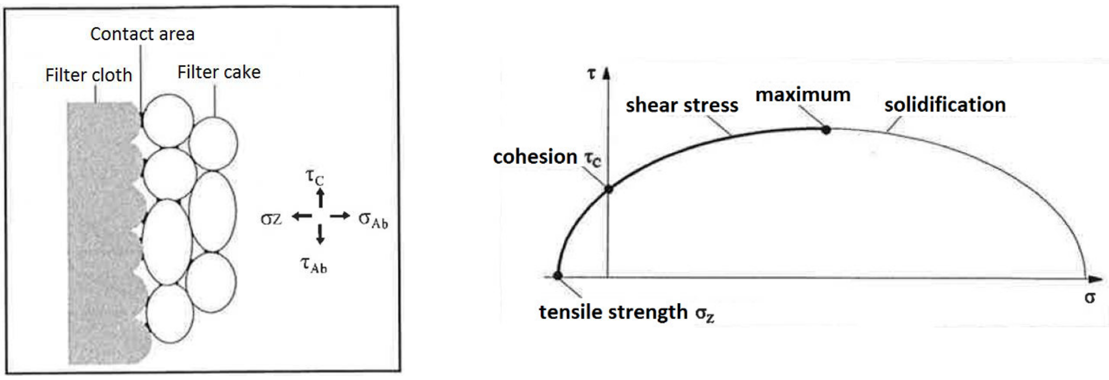


Figure 3: Schematic illustration of the effective forces, based on [7]

The evaluation of backwash treatment is here carried out in an experimental pilot plant, shown in Figure 4. For the optical observation of the discharge kinetics of the filter cake, a transparent PMMA-tank is used (B100). The required pressure drop between suspension and filtrate is generated by a vacuum-station. It is assumed, that the influence of the process condition "pressure difference" does not depend on the method used to generate the pressure gradient (vacuum- and pressure-filter) for filtration. The driving force behind the forming filter cake structure is only dependent on the scalar quantity of the pressure difference and the process conditions (particle system, weave type, pH-value etc.). With the suspension-vessel (B101), the filter cake would be built up until a defined thickness is reached. Then, the suspension must be flushed out with clean water (B102). It is important to maintain the pressure difference without interruption. Following, the discharge can be observed optically. For this, the filter cake will be discharged through a water pulse, supplied by the backwash-vessel and will be observed by a camera.

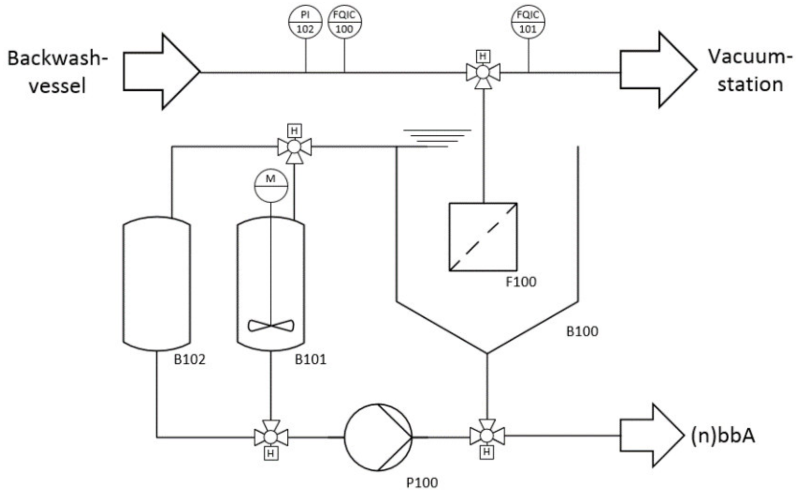
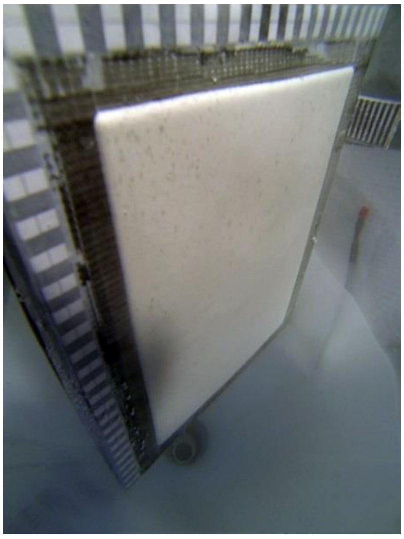


Figure 4: Schematic flow chart of the experimental plant

For each trial, a filter cake of defined thickness is built up and discharged. A reproducible filter cake can be created by adjusting the volumetric flow $\dot{V}_F$ (Δp=const.) and using the Darcy-Equation, converted to the filter thickness H (Equation 1). The filter cloth resistance R_F and filter cake resistance α_H are determined experimentally with a pressurized nutsch filter and verified with laser-distance measurement. The viscosity η_f is assumed with 10^{-3} Pa·s.

$$H = \frac{\left(\frac{\Delta p \cdot A}{\eta_f \cdot \dot{V}_f}\right) - R_F}{\alpha_H} \qquad \text{(Eq.1)}$$

The required backwash pressure and the corresponding backwash volume by given process conditions will be recorded. For a systematic process evaluation, the beginning of regeneration will be announced by a LED and is finished when the filter cake reaches the middle of the filter disc. An example of a filter cake discharge is shown in Figure 5 for an approximately 2 mm filter cake, consisting of Eskal 100 with a modal value of 6,5 µm and a metallic filter cloth from Fa. GKD with 9 µm geometric pore size (Optimized Dutch Weave). The filter cake is dropped into water as continuous phase.

a) 

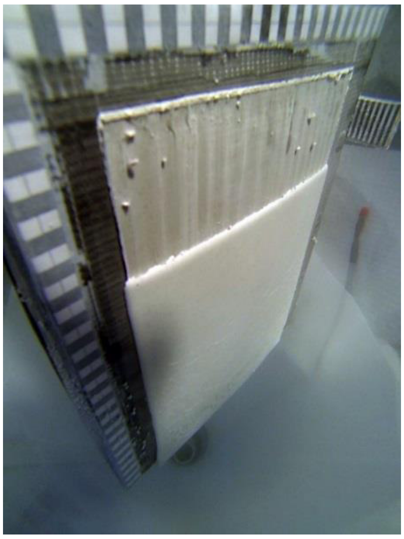
b) 

Figure 5: Build-up filter cake, consisting of Eskal 100, with 2 mm thickness and a surface area of A=300 cm² before (a) and during regeneration (b)

With respect to the field of applications, the removal procedure has revealed that there is potential for improvement in pressure difference and amount of backwash reflux. These process variables highly depend on the material properties like cohesion within the filter cake and adhesion of the filter cake onto the filter media. In order to guarantee the removal of the filter cake, the applied removal force has to be larger than the adhesive forces. Furthermore, to remove the filter cake in large fragments, the removal force has to be lower than the cohesive force [3, 4]. These two effects depend on porosity, pH-value, continuous phase for cake removal (gas or liquid) and additional properties.

In this first backwash study, Eskal 100 is characterized by strong stability of the filter cake and removal of large pieces. The filter cake has been discharged at various filter cake thicknesses, shown in Figure 6. The experiments show, that the thickness of the filter cake has no significant influence on the backwash volume. With the consideration that the filter cake resistance α_H inside the filter cake is approximately 10^{14} m^{-2}, the backwash volume which passes through the filter cloth builds a thin water film. This film removes the first particle layer and the filter cake can slide up. This adhesion force is independent of the filter cake thickness.

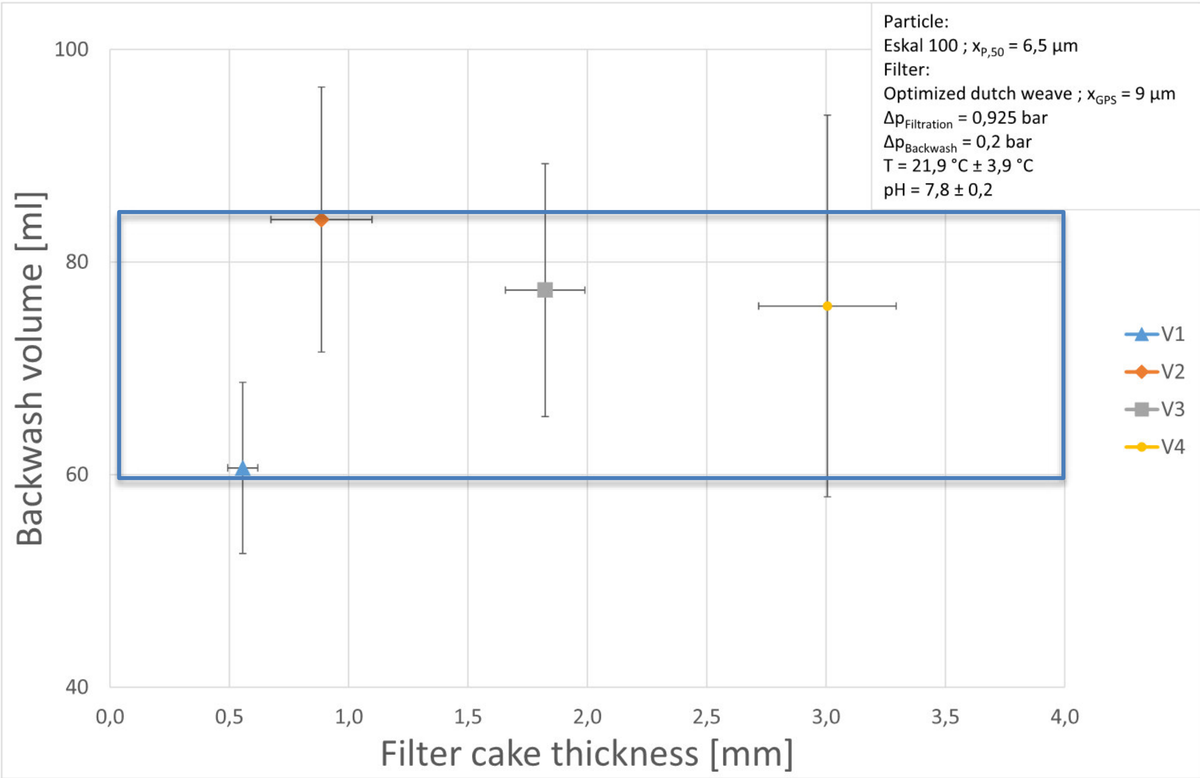


Figure 6: Backwash volume as a function of the filter cake height

In the next phase, experiments for further process conditions by regeneration of a filter cloth in vacuum-operation are planned in combination with regenerating filter cloth under pressure filtration conditions. In addition to the investigation with a metallic filter cloth, some polymer filters will be part of the future investigation. Actual studies with a 12 µm and 22 µm polymer filter have already carried out and show that the backwash volume increase in those cases. Currently, this behavior is attributed to the smaller Young's modulus [8] and the expansion volume through the backwash flow.

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